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REFLECTION TYPE COLOR DISPLAY DEVICE
[HANSHA KATA KARAA-HYOJI SOCHI]

SHIGERU YAMAMOTO ET AL

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[Title of Invention] Reflection type color display device

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[Scope of Patent Claims]

[Claim 1] In a reflection-type color display device wherein the two states of reflecting and absorbing specific wavelength regions can be obtained selectively, and wherein multiple light-modulating elements are laminated to mutually differentiate the aforementioned specific wavelength regions: a reflection-type color display device characterized in that said multiple light-modulating elements are each provided with a dichroic mirror for reflecting selectively the respective aforementioned specific wavelength regions, and a light-modulating layer, provided at the external incident ray side of said dichroic mirrors, having dichroism and substantially allowing the passage of other wavelength regions.[1]

[Claim 2] The reflection-type color display device stated in Claim 1, wherein the aforementioned multiple light-modulating elements are three light-modulating elements that possess red, green, blue wavelength regions respectively as the specific wavelength regions.

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[1] the numbers in the margin indicate pagination in foreign text

[Claim 3] The reflection-type color display device stated in Claim 2, wherein the three light-modulating elements are laminated so that the specific wavelength regions are, in sequence from the external incident ray side, green, red, and blue wavelength regions.

[Claim 4] The reflection-type color display device stated in any of the Claims 1 - 3, wherein each dichroic mirror of the aforementioned light-modulating elements is formed adjacent to the aforementioned light-modulating layer of the respective light-modulating element by means of a dielectric multilayer film.

[Detailed explanation of the invention]

[0001]

[Technological field of the invention] The invention pertains to a reflection-type color display device in which multicolor display is possible.

[0002]

[Prior Art] The increase in demand for portable information devices such as notebook computers and PDAs (Personal Digital Assistants) has been accompanied by the need for flat panel displays with high display quality, in particular, flat panel displays able to display color. To realize this, research has focused heavily on the reflective type color display device.

[0003] Various systems have been offered as the reflection-type color display device. One example of a system able to realize reproduction of a broad range of colors and facilitate conversion to full color is the so-called guest-host 3 layered laminated system, such as was presented in the Proceedings of SID' 81 p22 1981 and SID' 96 Digest p103 - 106. In this system, laminated cells made from guest-host liquid crystals contained 2 color pixels, yellow and magenta respectively. In addition, a reflective plate was provided at the reverse side to the external incidence ray side.

[0004] Figure 4 shows an example of the reflection-type color display device of this guest-host 3-layered laminated system. When the planar oriented mode was used for the chiral nematic crystals, the light-modulating elements 10G, 10R, 10B formed from liquid crystal cells of the respective guest-host liquid crystals were laminated, and reflective plate 24 was also provided at the reverse side to the external incident ray side, as described above.

[0005] In each of the respective light-modulating elements 10G, 10R, 10B, transparent pixel electrodes 21, 22 made from material such as ITO were formed on each surface of the two transparent glass substrates 11, 12. The planar orientation process was applied, and the transparent substrates 11, 12 were bonded at a distance of between several micrometers and

several tens of micrometers. A mixture containing nematic liquid crystals having positive dielectric anisotropy, a chiral agent and dichroic pigments were introduced between the transparent substrates 11 and 12 to form the light-modulating layers 23M, 23C and 23Y.

[0006] Materials such as the generally available E-8 made by Merck Co. can be used as the nematic liquid crystal having positive dielectric anisotropy. In addition, generally available ZLI - 811, CB15 made by Merck Co. can be used as the chiral agent. A suitable amount of dichroic dyes of magenta, cyan and yellow respectively are mixed into the mixture of the nematic liquid crystal and chiral agent, to obtain 3 types of mixture that form the light-modulating layers 23M, 23C and 23Y respectively.

[0007] For the dichroic dyes of magenta, cyan and yellow, colors having absorption wavelengths with central values in the vicinity of 535 nm, 625 nm, 445 nm respectively can be used. M-618, SI-497, SI-486 respectively, made by Mitsuitoatsu Co. can be used.

[0008] Then, after the mixtures are poured into the respective cells, the inlets holes of the cells are sealed, and an electric field application means is provided to the transparent pixel electrodes 21, 22 in each cell. Then, the 3 cells, namely the light-modulating elements 10G, 10R and

10B, are placed in overlapping manner, the reflective plate 24 made from aluminum plate is provided on the reverse side to the external incident ray side, and the reflection-type color display device is thus obtained.

[0009] The orientation mode of the liquid crystal molecules in the center of the liquid crystal cells of the guest-host liquid crystal containing the dichroic dyes is not limited to the planar orientation mode of the chiral nematic liquid crystal as described above. For example, homogeneous orientation mode of the nematic liquid crystal can be used. However, a deviated plate is required in the case of the homogenous orientation. Also, the mode can be used in which dichroic dyes are added to polymer dispersed liquid crystal (PDLC), in which polymer in droplet form is dispersed in nematic liquid crystal.

[0010] A wide color reproduction range can be obtained in the reflective type color display device of the aforementioned guest-host 3 layers lamination system according to the same coloring principles as used in photocopying and printing.

[0011] However, this system consists of the light-modulating elements 10G, 10R, 10B each divided into pixel units, and each pixel requires a the driver part 25 consisting of wiring and switching element for driving each pixel. As a

result, the light incident on each pixel is hindered by the driver part 25. In addition, to improve the contrast in general, a black matrix 26 is provided on the transparent substrate 11 of the external light incident side of the respective light-modulating elements 10G, 10R, 10B.

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[0012] Thus, the usage efficiency of the light is in the region 70 - 80% for each passage of light through one light-modulating element. As in the example of figure 4, when the green light 1G, the red light 1R and the blue light 1B in the incident light are observed as reflected light by passing through the respective 3 layers of light-modulating elements 10g, 10R, 10B, by the 6th passage at 80% efficiency, this becomes lower than 30 %.

[0013] Therefore, in the reflective type color display device of the aforementioned conventional guest-host system, vivid colors requiring brightness cannot be displayed. In particular, high reflective index was not obtained during the white color display when high brightness was required, and brightness was insufficient, which was a drawback.

[0014] Recent research has focused on the use of light-modulating elements based on interference reflection systems to serve as a reflective type color display device that can solve this problem. In the interference reflection system,

in theory a reflective index close to 100% is obtainable in the desired wavelength, and so a color display with high level of brightness is possible. An example of the light-modulating element based on this interference reflection system and a production method therefor was offered in Japanese Patent Publication No. 4-355424, as presented below.

[0015] That is, as shown in figure 5(A), mixture 80 containing the photo polymerized compound in the nematic liquid crystal having positive dielectric anisotropy is poured into the cell 70 facing at a certain distance a pair of transparent substrates 71, 73 formed with transparent electrodes 72, 74 at the internal sides respectively. Coherent light is radiated into cell 70 from both surfaces of cell 70, and the photopolymerizable compound in the mixture 80 was polymerized due to the interference from both sides.

[0016] At this time, as shown in figure 5(B), the polymerized compound formed the polymer layer 83 at the period determined by the incident angle and the wavelength of coherent light used for hologram writing. The nematic crystals were precipitated into the region outside of the polymer film 83, and the liquid crystal layer 85 was thus formed. Therefore, at the state when the voltage is not

applied between the transparent electrodes 72, 74, a periodic change in the refractive index is produced in the light modulating layer 81, and reflection of a specific wavelength can be produced.

[0017] Then, if the refractive index 'np' of the polymer and the refractive index 'no' in the normal light of the liquid crystal is the same, in the state when voltage is applied between the transparent electrodes 72, 74, the periodic change in the refractive index of the light-modulating layer 81 is eliminated by the orientation of the liquid crystal molecules in the electric field direction, and the incident light passes through cell 70. Therefore, the reflected light amount can be controlled according to the voltage applied between the transparent electrodes 72, 74.

[0018] In this system, in theory, the reflection wavelength can be selected by the incident angle or the wavelength of the coherent light for the hologram writing. Therefore, for example, by manufacturing and overlapping three light-modulating elements having red, green and blue wavelength regions as the reflection wavelength regions, and providing a light absorption layer at the external light incident side and the reverse side, a wide color reproduction range can be obtained and full color display is possible.

[0019] Then, according to this system, the light reflected by the light-modulating element at the outermost incident ray side is observed insofar as it makes a return trip through the light-modulating element at the outermost incident ray side, and is therefore only affected by the aperture ratio twice. Similarly, since the light reflected by the light-modulating element in the center is observed insofar as it makes a return trip through the light-modulating element in the center and the light-modulating element at the outermost incident ray side, it is only affected by the aperture ratio four times. Only the light reflected by the light-modulating element of the outermost incident ray side and the reverse side is observed by making a return trip through the light-modulating element of all the 3 layers.

[0020] Therefore, by providing the light-modulating element in the outermost incident ray side reflecting the light of the color requiring most brightness, a bright display can be obtained as compared to the aforementioned conventional guest-host system. For example, by laminating the light-modulating elements in the order of green, red, blue from the external incident ray side, since this is the order of decreasing human sensitivity to brightness of color, for each of the colors green and red a reflective index can be

obtained which is higher than that of respective guest-host systems.

[0021]

[Problems to be resolved by the invention] However, as shown in figure 5 (C), in the light-modulating elements according to this interference reflective system, with the liquid crystal layer 85 only consisting of the liquid crystal 86, the liquid crystal 86 becomes dispersed in droplet form in the polymer 84 and the orientation of that liquid crystal droplet 86 becomes random.

[0022] Thus, the averaging effects of both the refractive index of the polymer 84 contained therein and the random orientation of the liquid crystal droplets 86 result in considerable reduction in the effective refractive index of the liquid crystal layer 85 and smaller fluctuations in the periodic refractive index in the light-modulating layer 81. Thus, the full width half maximum of the reflection spectral becomes narrow, and brightness becomes low when this is used as the display element.

[0023] Therefore, the as yet not widely known light-modulating element presented in the 1st, 2nd and 3rd examples of the previously filed Japanese Patent Application No. 8-226046 (August 7th, 1997)is given below.

[0024] As shown in figure 6, the light-modulating elements of the 1st example of the Prior Application consist of an light-modulating layer 50 held between transparent substrates 11, 12. This light-modulating layer 50 is formed of by alternating non-sensitive layers 51 (discussed later) and sensitive layers 52 in the Z axis (facing the direction of the transparent substrates 11, 12), each layer extending to form stripes in the X direction (the perpendicular direction to the Z axis direction) on the transparent substrate 12. A pair of electrodes 43, 44 is formed at opposing ends of the Y axis (direction perpendicular to the Z axis direction and the X axis direction).

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[0025]This light-modulating element is manufactured with the method shown below. First, the electrodes 43, 44 are formed on the transparent substrate 12, and a homogenous orientation process is applied on the transparent substrates 11, 12 respectively. The liquid crystals containing a small amount of the photopolymerized compound are poured into the cells bonded with the transparent substrates 11,'12 at a desired distance. Coherent light is radiated into the cell from both surfaces of the cell, to effect cyclic polymerization of the photopolymerizable compound. The non-sensitive layer 51, in which the orientation of the liquid

crystal molecules does not change, is formed by voltage applied between the electrodes 43, 44.

[0026] In addition, after exposure to light over a certain time, ultraviolet ray is radiated over the entire cell body. The orientation state of the liquid crystal is changed by the voltage applied between the electrodes 43, 44 between the non-sensitive layers 51, the sensitive layer 52 is formed.

[0027] As shown in figure 6(A), when the light-modulating element is in the state where voltage is not applied between the electrodes 43, 44, since the liquid crystal molecules in the light-modulating layer 50 are not oriented uniformly in the X axis in either the non-sensitive layer 51 or sensitive layer 52, no difference between refraction indexes is generated between the non-sensitive layer 51 and the sensitive layer 52, and reflected light is not generated.

[0028] In contrast to this, in the state when sufficient voltage is applied between the electrodes 43, 44, by the application of the electric field in the Y axis direction in the light-modulating layer 50, as shown in figure 6(B), the orientation direction of the liquid crystal molecules in the sensitive layer 52 is changed to the Y axis direction. Thus, refractive index difference is generated between the non-sensitive layer 51 and the sensitive layer 52. That is,

periodic change in the refractive index is generated in the Z axis direction in the light-modulating layer 50, and reflected light is generated.

[0029] When the light-modulating element is in the reflection state of figure 6(B), the liquid crystal in the non-sensitive layer 51 is oriented in the X axis direction, whereas the liquid crystal in the sensitive layer 52 is oriented in the Y axis direction. Therefore the refractive index difference between the non-sensitive layer 51 and the sensitive layer 52 is substantially equal to the refractive index of the liquid crystal and extremely large, allowing a sufficiently wide full-width half-maximum reflection spectral to be obtained.

[0030] As shown in figure 7, in the light-modulating element of the 2nd example of the Prior Application, the light-modulating layer 50 is held between the transparent substrate 11 on which is formed the transparent electrode 41, and the transparent substrate 12 on which is formed the transparent electrode 42. This light-modulating layer 50 is formed so that the liquid crystal molecules oriented in the X axis in the 1st layer 55 alternate, in the Z axis direction, with those oriented in the Y axis direction in the 2nd layer 56.

[0031] This light-modulating element is manufactured with the method shown below. First, the transparent electrodes 41, 42 are formed on the transparent substrates 11, 12, and the homogenous orientation process is applied. The liquid crystals containing a small amount of photopolymerizable compound are introduced into the cells, with transparent substrates 11, 12 bonded at a desired distance. Coherent light is radiated onto the cell from both surfaces of the cell to effect cyclic polymerization of the photopolymerizable compound, and the liquid crystal molecules are oriented and fixed in the X axis direction to form the 1st layer 55.

[0032] In addition, with a sufficiently strong magnetic field applied in the Y axis direction, ultraviolet light is radiated over the entire cell body so that between the 1st layer(s) 55 the liquid crystal molecules are oriented and fixed in the Y axis direction to form the 2nd layer 56.

[0033] As shown in figure 7(A), when the light-modulating element is in the state where voltage is not applied between the transparent electrodes 41, 42, since the liquid crystal molecules in the light-modulating layer 50 are oriented in the X axis direction in the 1st layer 55 and oriented in the Y axis direction in the 2nd layer 56, the refraction index difference is generated between the 1st layer 55 and the 2nd

layer 56. That is, periodic change is generated in the refractive index in the Z axis direction in the light-modulating layer 50, and reflected light is generated.

[0034] In contrast to this, in the state when voltage is applied between the electrodes 41, 42, by the application of the electric field in the Z axis direction in the light-modulating layer 50, as shown in figure 7(B), the orientation direction of the liquid crystal molecules in the 1st layer 55 and the orientation direction of the liquid crystal molecules in the 2nd layer 56 is changed in the Z axis direction. Thus, refractive index difference is not generated between the 1st layer 55 and the 2nd layer 56, and the reflected light is eliminated.

[0035] In the reflection state of figure 7(A) obtained by this light-modulating element, the refractive index difference between the 1st layer 55 and the 2nd layer 56 is substantially equal to the refractive index of the liquid crystal, becoming extremely large and allowing a sufficiently wide full-width half-maximum reflection spectral to be is obtained.

[0036] The light-modulating element of the 3rd example of the Prior Application is shown in figure 8. The light-modulating layer 50 is held between the transparent substrate 11 on which is formed the transparent electrode 41,

and the transparent substrate 12 on which is formed the transparent electrode 42. The light-modulating layer 50 is formed of a liquid crystal polymer complex consisting of a polymer matrix through which are dispersed nematic liquid crystal droplets having positive dielectric anisotropy, and formed such that the 1st layer 57 of liquid crystals oriented in the X axis direction alternates, in the Z axis direction, with a 2nd layer 58 of liquid crystals oriented in the Y axis direction.

[0037] This light-modulating element is manufactured with the method shown below. First, the transparent electrodes 41, 42 are formed on the transparent substrates 11, 12.

[0038] Next, the processes (1) - (4) shown below are repeated 10 times on the transparent substrate 12 on which is formed with the transparent electrode 42, thus forming the light-modulating layer 50.

(1) The liquid mixture of solvent, photopolymerized compound and nematic liquid crystal having positive dielectric anisotropy are spin coated onto the transparent substrate 12, and the solvent is evaporated.

(2) The work is transferred into a chamber filled with nitrogen. While applying a magnetic field in the Y axis direction using a superconductive magnet, ultraviolet light is radiated over the entire transparent substrate 12 to form

a polymer dispersion liquid crystal layer constituting the 2nd layer 58.

(3) The aforementioned liquid mixture is spin coated onto the transparent substrate 12, and the solvent is evaporated.

(4) The work is transferred into the chamber filled with nitrogen. While applying a magnetic field in the X axis direction using a superconductive magnet, ultraviolet light is radiated over the entire transparent substrate 12 to form the polymer dispersion liquid crystal layer constituting the 2nd layer 57.

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[0039] The thickness of one layer of the liquid crystal polymer complex after curing becomes in the region of 80 nm. Finally, the transparent substrate 11 on which is formed the transparent electrode 41 is bonded onto the light-modulating layer 50.

[0040] As shown in figure 8(A), when this light-modulating element is in the state where voltage is not applied between the transparent electrodes 41, 42, since the liquid crystal molecules in the light-modulating layer 50 are oriented in the X axis direction in the 1st layer 57 and oriented in the Y axis direction in the 2nd layer 58, a refraction index difference is generated between the 1st layer 57 and the 2nd layer 58. That is, periodic change is generated in the

refractive index in the Z axis direction in the light-modulating layer 50, and reflected light is generated.

[0041] In contrast to this, in the state when voltage is applied between the electrodes 41, 42, by the application of the electric field in the Z axis direction in the light-modulating layer 50, as shown in figure 8(B), the orientation direction of the liquid crystal molecules in the 1st layer 57 and the orientation direction of the liquid crystal molecules in the 2nd layer 58 are changed to the Z axis directions. Thus, refractive index difference is not generated between the 1st layer 57 and the 2nd layer 58, and reflected light is eliminated.

[0042] In the reflection state of figure 8(A) obtained by this light-modulating element, the refractive index difference between the 1st layer 57 and the 2nd layer 58 is substantially equal to the refractive index of the liquid crystal, becoming extremely large and allowing a sufficiently wide full-width half-maximum reflection spectral to be obtained.

[0043] As described above, in the light-modulating element in the 1st, 2nd and 3rd examples of the Prior Application, according to the voltage applied between the transparent electrodes 41, 42 or electrodes 43, 44, the light in a specific wavelength region is reflected, or the light in all

wavelength regions is allowed to pass through. Therefore, by for example overlapping 3 light-modulating elements manufactured so that the reflection wavelength regions are set as red, green and blue wavelength regions respectively, and providing a photo absorption layer on the external incident ray side and the reverse side, reproduction of a wide color range can be obtained, and full color display become possible.

[0044] In addition, as described above, the periodic refractive index fluctuations in the light-modulating layer 50 in the reflected state become extremely large, allowing sufficiently wide full-width half-maximum reflection spectral to be obtained, and when this is used as the display element, brightness is increased sufficiently and extremely good display characteristics are obtained.

[0045] However, because the light-modulating element of the 1st example of the Prior Application, as shown in figure 6, is provided with electrodes 43, 44 for applying the electric field in the plane of the substrates 11, 12 inside the pixels, the aperture ratio of the pixels are reduced significantly. In addition, if the driving of the electric field in that plane is considered, the threshold voltage Vt between the permeation state and the reflection state is:

$Vt = (\pi L/d) \times (k2/\varepsilon o\Delta\varepsilon)1/2$ (1)

L is the distance between the electrodes 43, 44, d is the thickness of the light-modulating layer 50, k2 is the twist elasticity of the liquid crystal, $\Delta\varepsilon$ is the dielectric anisotropy of the liquid crystal.

[0046] Since d corresponds to the thickness of each layer forming the periodic structure, it is the value corresponding to the light wavelength, and is extremely small, being in the region of several tens to several hundreds of nanometers. Thus, extremely high voltage is required as the threshold voltage Vt, making the element difficult to drive while at the same time increasing power consumption.

[0047] Also, in the light-modulating element in the 2nd and 3rd examples of the Prior Application, shown in figures 7 and 8, because the production process involves controlling the orientation direction of the liquid crystal molecules by applying a magnetic field, an extremely strong magnetic field is required. Therefore, it is difficult to apply the magnetic field uniformly over a wide surface area, creating problems in terms of productivity and uniformity of the element.

[0048] Therefore, the present invention is designed to offer a reflection-type color display device with multicolor display, that can not only realize reproduction of a wide

color range, but can also obtain a bright display, in particular greatly improving the brightness of white color display and providing better visibility, together with simplification in the production and driving of the device.

[0049]

[Means for Resolving the Problem] This invention provides, in a reflection-type color display device wherein the two states of reflecting and absorbing respective specific wavelength regions can be obtained selectively, and wherein multiple light-modulating elements are laminated to mutually differentiate the aforementioned specific wavelength regions, a reflection-type color display device characterized in that said multiple light-modulating elements are provided with dichroic mirrors for reflecting selectively the respective aforementioned specific wavelength regions, and light-modulating layers, provided at the external incident ray side of said dichroic mirrors, having dichroism and substantially allowing the passage of other wavelength regions.

[0050] In this case, said multiple light-modulating elements can be three light-modulating elements such that the specific wavelength regions are red, green and blue wavelength regions respectively.

[0051] In this case, it is preferred that the three light-modulating elements are laminated such that said specific wavelength regions are in the order green, red and blue wavelength regions from the external light incident side.

[0052] Also, it is preferred that the dichroic mirrors of the respective light-modulating elements are formed by dielectric multilayered film, adjacent to the aforementioned light-modulating layer of each light-modulating element.

[0053]

[Action] In a typical case of the three light-modulating elements after lamination, the reflection-type color display device of the invention constituted as described above consists of a 1st layer constituting the light-modulating element at the outermost incident ray side, a 2nd layer constituting the intermediate light-modulating element, and a 3rd layer constituting the light-modulating element on the side opposite the outermost incident ray side. In this case, light of the 1st color passes through the 1st light-modulating layer and is reflected by the dichroic mirror on the 1st layer. Insofar as it makes a return trip through the 1st layer light-modulating element, this light is observed as reflected light and is only affected by the aperture ratio two times.

[0054] Also, after passing through the 1st light-modulating layer and dichroic mirror and the 2nd light-modulating layer, light of the 2nd color is reflected by the 2nd layer dichroic mirror. Insofar as it makes a return trip through the 1st and 2nd layer light-modulating elements, this light is observed as reflected light and is only affected by the aperture ratio four times.

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[0055] Only light of the 3rd color is reflected by the 3rd layer dichroic mirror, first passing through the 1st and 2nd light-modulating layers and dichroic mirrors, and the 3rd light-modulating layer, and by making a return trip through all three layers of light-modulating elements, this light is observed as reflected light.

[0056] Therefore, a bright display can be obtained by making the 1st layer the light-modulating element which reflects, by dichroic mirror, light of a color that needs to be particularly bright.

[0057] When the light-modulating elements in the 1st, 2nd and 3rd layers are such that the wavelength regions of green, red and blue respectively are reflected by the dichroic mirrors, the light-modulating elements are arranged from the viewing side in the order of decreasing brightness of color according to human sensitivity. Therefore vivid

colors can be represented, and in particular the brightness of white color display is improved greatly.

[0058] Also, when the dichroic mirrors of each light-modulating element are formed by dielectric multilayered film, adjacent to the light-modulating layer of that light-modulating element, respective dichroic mirrors are placed at the inner sides of the substrates constituting the light-modulating elements, and the effect of the aperture ratio of the light-modulating element on the reflected light is equivalent to a substantially one-way trip, resulting in an improved reflection rate over all wavelength regions.

[0059]

[Embodiments of the Invention] Figure 1 shows an example of the reflection-type color display device of this invention. In this case the three light-modulating elements 10G, 10R, 10B are laminated.

[0060] For the light-modulating elements 10G, 10R and 10B respectively, a black matrix 26, a driver part 25 made up of thin film transistor switching elements, wiring, etc., and the transparent pixel electrode 21 made of ITO are formed on one surface of the transparent glass substrate 11 to manufacture the active matrix substrate. The dichroic mirrors 27G, 27R, 27B are formed by the dielectric multilayered film on one surface of the transparent

substrate 12 made of glass, and the transparent pixel electrode 22 made of ITO is formed over each mirror, thus manufacturing the opposite substrate. The planar orientation process is then applied on the surface of each of the transparent pixel electrodes 21, 22. Then, the transparent substrates 11, 12 are bonded at a distance of several micrometers to several tens of micrometers so the transparent pixel electrodes 21, 22 are at the internal side, and the cell is thus manufactured.

[0061] The dichroic mirrors 27G, 27R, 27B formed by dielectric multilayered film are formed to possess the following reflection wavelength regions: the dichroic mirror 27G is 490 nm - 580 nm, the dichroic mirror 27R is ≥580 nm, the dichroic mirror 27B is ≤490 nm. Specifically, ZrO2 can be used as the high refraction index film, MgF2 can be used as the low refraction index film, and each film is formed by electronic beam deposition.

[0062] The bandwidth and the central wavelength in the reflection wavelength regions of the dichroic mirrors 27G, 27R, 27B can be easily controlled by the thickness of the periodic film, the ratio of the respective refractive indexes and the ratio of the film thicknesses.

[0063] Then, the mixture consisting of the dichroic dyes, the chiral agent, and the nematic liquid crystals having

positive dielectric anisotropy is poured into the cells of the respective light-modulating elements 10G, 10R and 10B to form light-modulating layers 23M, 23C and 23Y, and the inlet holes are sealed.

[0064] Widely available E-8 made by Merck Co. can be used as the nematic liquid crystals having positive dielectric anisotropy. Widely available ZLI-811, CB15 made by Merck Co. can be used as the chiral agent. The mixing ratio of the nematic liquid crystals and the chiral agent can be adjusted so the selected reflected wavelength is not in the visible region for the chiral nematic liquid crystal.

[0065] The following are mixed into the mixture of nematic liquid crystals and chiral agent: for the light-modulating layer 23M, magenta dichroic dye with central absorption wavelength value in the region of 535 nm; for light-modulating layer 23C, cyan dichroic dye with central absorption wavelength value in the region 625 nm; for the light-modulating layer 23Y, yellow dichroic dye with central absorption wavelength value in the region 445 nm. For the dichroic dyes of magenta, cyan and yellow respectively, M-618, SI-497, SI-486 made by Mitsuitoatsu Co can be used. The mixing ratio of dichroic dyes is determined to balance contrast and maximum permeability, but in general it is in the range of 0.5% to several percent.

[0066] It is clear from above that by combining in the same light-modulating element the dichroic dyes in the light-modulating layer and the dichroic mirrors, the absorbed color in the dichroic dye is the complementary color of the reflected color of the dichroic mirror. That is, the dichroic dye of magenta in the dichroic mirror 27G reflecting the green light 1G, the dichroic dye of cyan in the dichroic mirror 27R reflecting the red light 1R, and the dichroic dye of yellow in the dichroic mirror 27B reflecting the blue light 1B are combined respectively.

[0067] Liquid crystal driving means are connected to each of the light-modulating elements 10G, 10R and 10B manufactured as described above. The three light-modulating elements are then overlapped and bonded in the order 10G, 10R and 10B from the external incident ray side, thus completing the reflection-type color display device.

[0068] In the reflection-type color display device of this example, the green color 1G in the incident ray passes through the light-modulating layer 23M and is reflected by the dichroic mirror 27G, then passes again through the light-modulating film 23M and is observed as a reflected beam. The red light 1R passes through the light-modulating layer 23M, the dichroic mirror 27G and the light-modulating layer 23C and is reflected by the dichroic mirror 27R, then

passes again through the light-modulating layer 23C, the dichroic mirror 27G and the light-modulating layer 23M and is observed as reflected light. The blue light 1B passes through the light-modulating layer 23M, the dichroic mirror 27G, the light-modulating layer 23C, the dichroic mirror 27R and the light-modulating layer 23Y and is reflected by the dichroic mirror 27B, then passes again through the light-modulating layer 23Y, the dichroic mirror 27R, the light-modulating layer 23C, the dichroic mirror 27G and the light-modulating layer 23M and is observed as reflected light.

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[0069] The color reproduction range according to the reflection-type color display device of this example is presented in figure 2(A). The color reproduction range according to the reflection-type color display device of a conventional guest-host 3-layer lamination system as described above and shown figure 4 is presented in figure 2(B). The comparison results of both are shown in figure 3. The results are shown in terms of CIEL*a*b* color space, and in addition, in the comparison the aperture ratio of the light-modulating element of one layer was 80%, the dichroic ratio of the dichroic dyes was 10, and the reflection plate 24 of figure 4 had gain of zero.

[0070] It is clear from this that by the reflection-type color display device of the example shown in figure 1, the brightness of the white color display in particular is improved greatly compared to the conventional example shown in figure 4. In addition, the color gamut in the yellow, green and cyan directions is enlarged and the brightness is improved.

[0071] This is because, as described above, the green light 1G is observed as reflected light insofar as it is reflected by the dichroic mirror 27G, making a return trip from dichroic mirror 27G through the portion of the external incident ray side from the light-modulating element 10G, while the red light 1R is observed as reflected light insofar as it is reflected by dichroic mirror 27R, making a return trip through the portion of external incident ray side from the dichroic mirror 27R of the light-modulating element 10R and through the light-modulating element 10G.

[0072] Also, unlike the light-modulating element of the 1st example of the Prior Application as described above and shown in figure 6, the element does not require high voltage to be driven, and can therefore be driven easily. Similarly, unlike the light-modulating elements of the 2nd and 3rd examples of the Prior Application as described above and shown in figures 7 and 8, a strong magnetic field is not

required in the production process of the element, and the element can thus be manufactured easily.

[0073] The example of figure 1 is the case in which chiral nematic liquid crystal in the planar orientation is used as the light-modulating layers 23M, 23C, 23Y of the guest-host liquid crystal, but the invention is not limited to this example, and can for example use a combination of cells of nematic liquid crystal of homogenous orientation and a light deviation plate, or a polymer dispersed liquid crystal (PDLC), and similar effects can be obtained in both cases.

[0074]

[Effects of Invention] According to the invention as described above, in the reflection-type color display device with multicolor display, not only can a wide color reproduction range be realized, but also a bright display can be obtained, the brightness of the white color display in particular can be improved greatly, visibility is improved, and in addition the driving and manufacturing of the device is simplified.

[Brief explanation of the diagrams]

Figure 1 shows an example of the reflection-type color display device of the invention.

Figure 2 shows a comparison of the color reproduction range according to the reflection-type color display device of

figure 4 and the color reproduction range according to the reflection-type color display device of figure 1.

Figure 3 shows a comparison of the color reproduction range according to the reflection-type color display device of figure 4 and the color reproduction range according to the reflection-type color display device of figure 1.

Figure 4 shows an example of the conventional reflection-type color display device.

Figure 5 shows an example of a conventional light-modulating element.

Figure 6 shows the light-modulating element of the 1st example of the Prior Application.

Figure 7 shows the light-modulating element of the 2nd example of the Prior Application.

Figure 8 shows the light-modulating element of the 3rd example of the Prior Application.

[Description of the symbols]

10G, 10R, 10B - light-modulating elements

11, 12 - transparent substrate

21, 22 - transparent pixel electrode

23M, 23C, 23Y - light-modulating layer

25 - driver part

26 - black matrix

27G, 27R, 27B - dichroic mirror

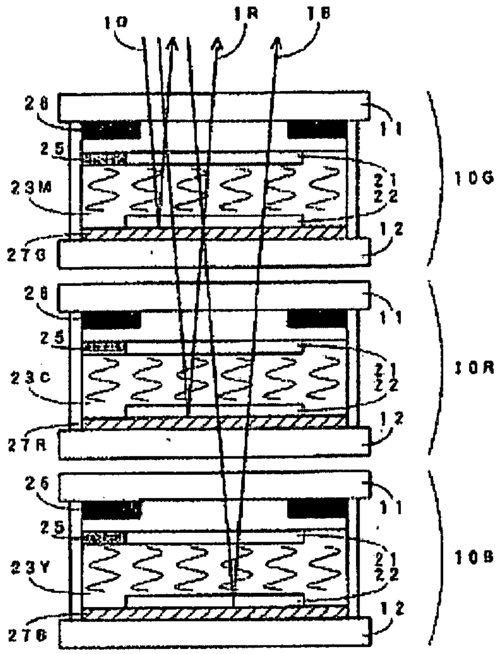


Figure 1

(A) Color reproduction range of the embodiment

	Y	G	C	B	M	R	W	K
L	77.59	72.20	72.82	28.77	39.97	39.87	78.14	27.04
a*	-39.02	-79.78	-64.92	17.49	48.03	33.44	-28.97	-16.80
b*	75.68	68.45	22.67	-39.85	-20.48	33.79	31.72	13.40

(B) Color reproduction range of a conventional example

	Y	G	C	B	M	R	W	K
L	46.84	35.22	39.22	17.73	28.35	28.21	49.79	13.87
a*	-2.05	-34.89	-19.80	33.47	46.65	34.38	2.72	4.31
b*	45.88	26.30	-19.18	-48.35	-38.15	18.69	-1.24	-2.11

Figure 2

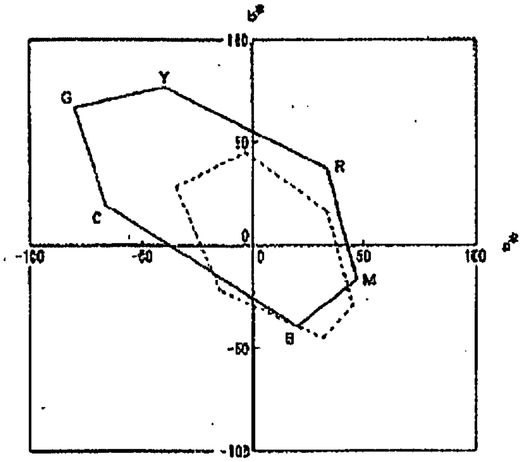


Figure 3

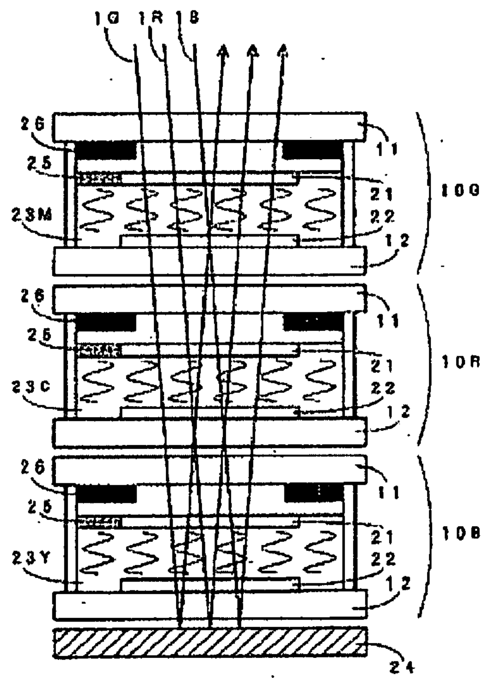


Figure 4

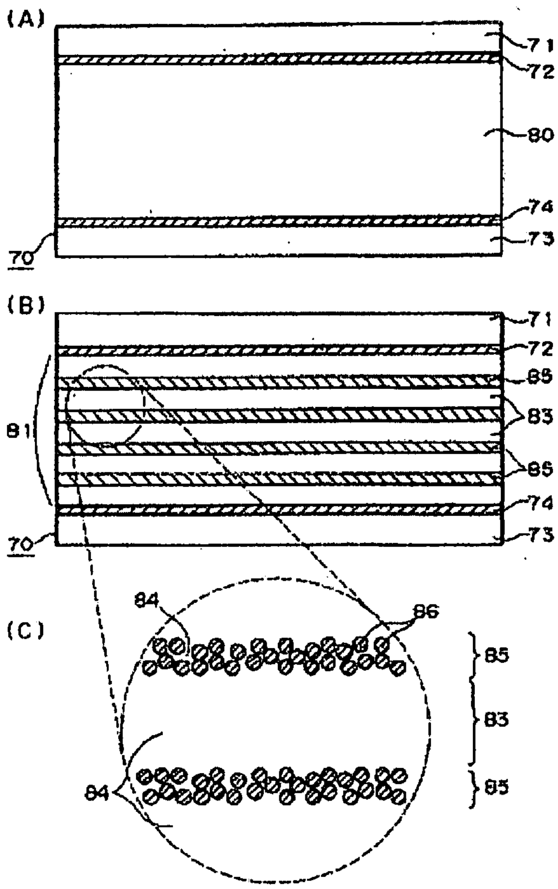
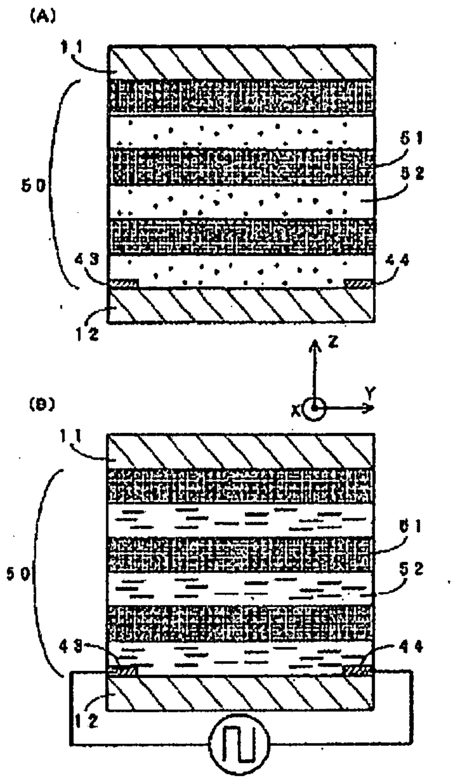


Figure 5



[Figure 6]

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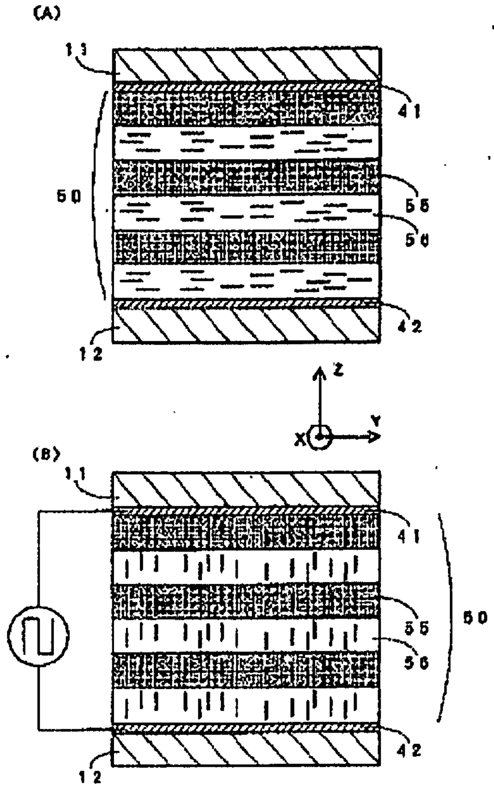
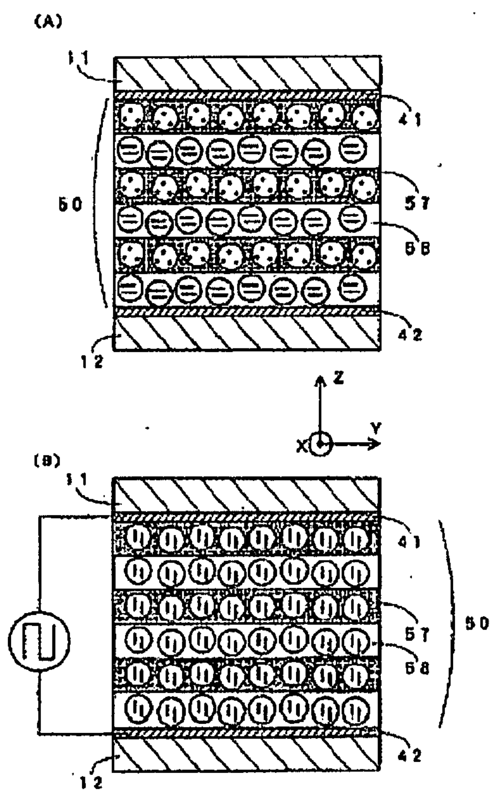


[Figure 7]



[Figure 8]